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The Yellows Disease of Carrot

By G. E. R. Hervey and W. T. Schroeder

Injury Caused by Carrot Yellows, with Healthy Root on Right.

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THE YELLOWS DISEASE OF CARROT

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ABSTRACT

THE carrot yellows disease has been studied under western New York conditions during the past three seasons. The virus in this area is transmitted solely by the six-spotted leafhopper, *Macrosteles divisus* Uhl. This species overwinters in the egg stage on grains and grass of which barley is a favorite host. The first generation of the leafhopper is spent on the winter host. As these insects mature, they fly to other hosts which include various weeds, carrots, and other cultivated crops. Since the virus is unable to overwinter in the leafhopper egg, the spring generation of the insect becomes infected through feeding on diseased perennial or biennial weeds.

Experiments are reported showing that the disease may be controlled in carrots by spraying with DDT to kill the leafhoppers. Three treatments applied during the period of maximum leafhopper abundance, namely, during late July and in August, gave 75 to 80 per cent reduction of the disease. Sprays proved superior to dusts. Best results were obtained with a DDT spray containing 0.5 per cent petroleum oil.

Susceptibility studies were made on various strains and varieties of both foreign and domestic carrots under field and greenhouse conditions. Some differences in response were noted under field conditions, but this is attributed more to leafhopper preference than the occurrence of an inherent physiological resistance to the disease. Morse's Bunching and Nanchan were the varieties least affected by yellows in the field trials.

INTRODUCTION

CARROT yellows is caused by the aster yellows virus and is transmitted in western New York by the six-spotted leafhopper (Fig. 1), *Macrosteles divisus* (Uhl.). The yellows disease of aster and other plants has been known since the turn of the century. Smith (22)[2] in 1902 described the symptoms of the disease on aster, but it was

[1] The writers wish to express their appreciation to Messrs. Jacob Fredericksen, Flint, N. Y.; Glenn Jensen, Seneca Castle, N. Y.; and Howard Utter, Flint, N. Y., for their interest and cooperation in the field experiments.

[2] Figures in parenthesis refer to Literature Cited, page 28.

not until 1924 that the cause of the disease was demonstrated by Kunkel (10) to be a virus. The chief mode of transmission was shown by Kunkel to be by the six-spotted leafhopper.[3] He also found the virus could be transmitted by budding but not by other mechanical means. The disease was transmitted to more than 50 species in 23 families of plants. Many additional hosts have been found in recent years.

Fig. 1.—The six-spotted leafhopper, *Macrosteles divisus* (Uhl.), greatly enlarged. This insect is the only known carrier of the virus of the carrot yellows in western New York.

Carrot was not included in Kunkel's original list of susceptible plants. In 1929, Whetzel (23), Folsom (3), and Zundel (25), working independently, observed a yellows disease on carrot in plantings in New York, Maine, and Pennsylvania, respectively. They suggested that it might be identical with the aster yellows described earlier by Kunkel. Severin (17) reported similar observations in California in 1929 and demonstrated that the disease on carrot was caused by the aster yellows virus and was transmitted by the six-spotted leafhopper. Since then, Severin (20) has found that 16 species of leafhoppers are capable of transmitting the California strain of aster yellows. No vector other than *M. divisus* (Uhl.) has been reported in New York.

Whetzel's report in 1929 appears to be the first record of the occurrence of the aster yellows virus on carrot in New York. These observations were made in the vicinity of Williamson on muck lands. He found that the infection ranged from a trace to 2 per cent in all but one field where about 25 per cent of the carrots were infected. Newhall (12) reported the disease in trace amounts in the same area in 1930. Further occurrence of the disease in New York State was not

[3] Kunkel referred to this species under the name of *Cicadula sexnotata* Fall, but Dorst (2) considers this name a synonym of *Macrosteles divisus* (Uhl.).

reported until 1944 when Schroeder (16) recorded an average infection of 30 per cent, with a range in individual fields of from 5 to 52 per cent in carrots growing on upland soils in Ontario County. Subsequent surveys made by the writers, mostly on upland soils, show average infections of 28, 53, 35, and 25 per cent, respectively, for the years 1945 through 1948. In 1946, the year of the highest disease incidence, some individual fields showed as much as 85 per cent diseased carrots.

Since the survey of 1944 indicated that commercial damage was being done by the disease, it was deemed advisable to initiate a program of research on the problem. The studies reported herein cover the period from 1945 through 1948 and were designed primarily to study the disease in relation to: (a) life history and habits of the vector, (b) a practical control of the disease by means of controlling the vector, and (c) the inherent reaction of domestic and foreign varieties of carrot to the aster yellows virus under western New York conditions.

SYMPTOMS AND EFFECT OF THE DISEASE ON THE CROP

The extent of the injury to the crop from carrot yellows depends for the most part on the severity of the disease, which in turn depends on the age of the plant when it is attacked and the length of time the disease has to develop before the crop is harvested. The disease is therefore more serious on the late-harvested crop grown for processing because of the longer growing season.

The first symptom noticed in the field is a yellowing of the younger leaves at the center of the crown. Later, such plants display a mass of adventitious chlorotic shoots that give a witches broom effect to the tops (Figs. 2 and 4). As the adventitious shoots develop, the petioles of the older leaves may become twisted and eventually break off. As a result, the short thick tufts of shoots remaining cannot be picked up readily by the mechanical harvester and many are left on the ground. For example, in one field showing 12 per cent yellows in 1948, only one-fourth of the diseased carrots were picked up by the mechanical harvester. Likewise, where the crop is harvested by hand, workers are reluctant to take time to twist off the bushy tops, which also results in many roots being left on the ground. The older leaves usually become bronzed and reddened, especially during the latter part of the season, although this symptom is not always associated with the disease. The bushy tops are unsightly and thus are con-

sidered objectionable where the crop is sold as bunched carrots on the retail market. In addition, these bushy tops predispose the roots to various soft rots which cause decay both in the field and in storage

Fig. 2.—Typical symptoms of carrot yellows. Diseased plant on left shows the characteristic bushy tops, the woolly roots, clinging soil particles, and tapered root. Virus-free plant on right.

(Fig. 3). In a field showing considerable sclerotinial crown rot at harvest time in 1946, almost without exception the only plants showing the rot were those which had yellows and the accompanying bushy tops.

Carrot yellows also may lower the yield of the crop by reducing the size of the root, especially if the infection occurs early and the crop is sold on a graded basis. (See frontispiece.) Plants infected very early may die before reaching maturity.

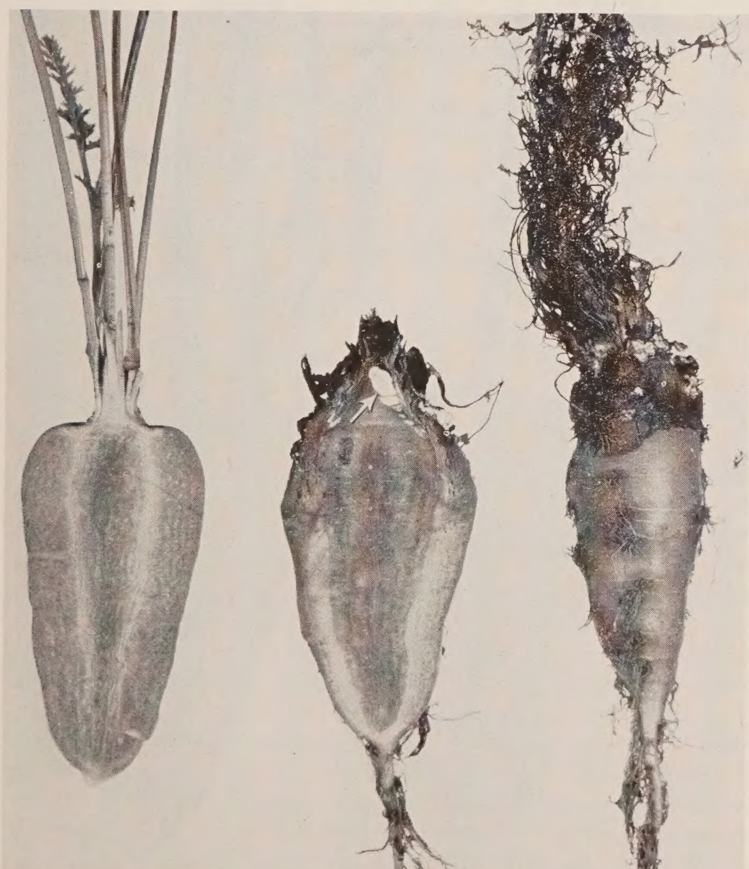

Fig. 3.—Soft rot damage on carrots previously infected with yellows. Cross section of sclerotial bodies indicated by arrow. Healthy carrot on left.

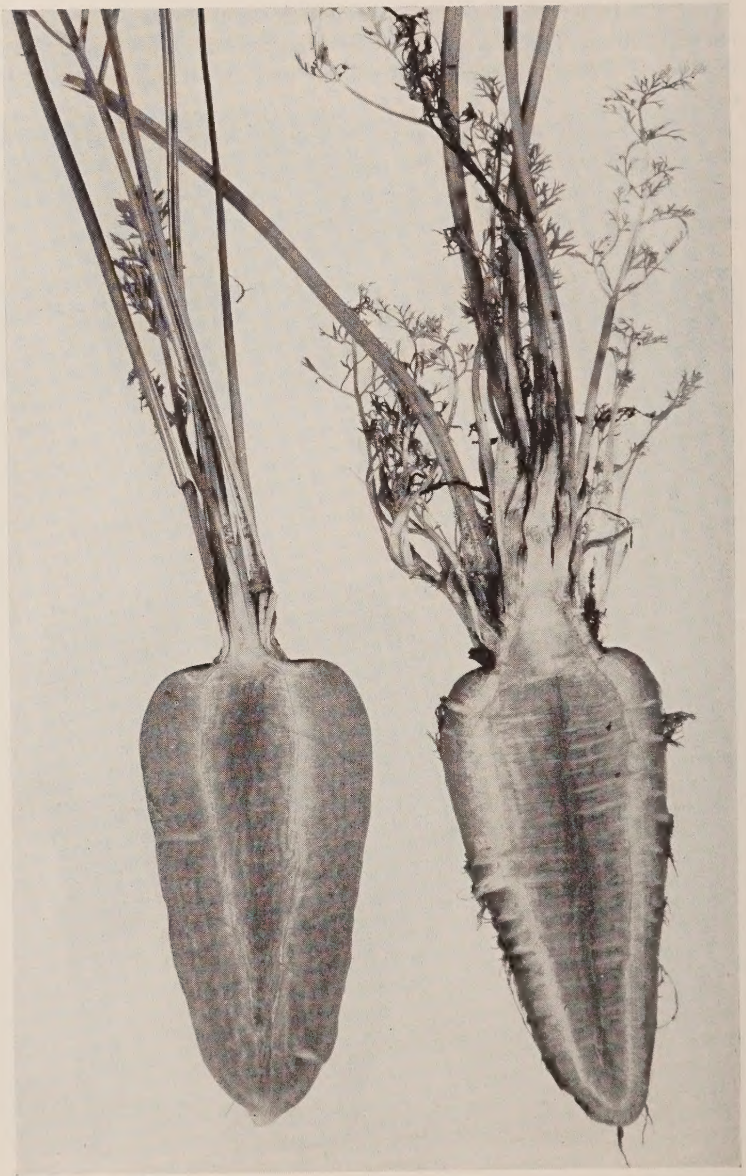

FIG. 4.—Longi-section of carrot roots, showing at right the structural modifications induced by carrot yellows. Note bushy top, the raised crown, the disproportionate amount of core, the tapered root, and the outgrowth of adventitious roots. Healthy plant on left.

The stunting of the root also may be accompanied by various structural modifications. Most striking of these is the development of woolly secondary roots, usually in four rows along the axis of the main root (Figs. 2 and 4). This condition is objectionable from the standpoint of appearance on market carrots. With canning carrots, the soil clings tenaciously to these roots and this frequently results in bringing in large amounts of soil in the crates (Fig. 2). The xylem or core of the root is usually enlarged, translucent when viewed in cross section, and extended upward into a raised crown (Fig. 4). It may also be somewhat lighter in color. On the Chantenay variety the diseased root is often rather tapered and does not round off into the blunt shape characteristic of the variety.

One of the most serious aspects of yellows from the standpoint of quality is the off-flavor it imparts to the processed product. This was pointed out by Hervey, *et al.* (8) who showed that the presence of yellows-infected carrots in canned or frozen purees imparted a bitter astringent flavor to the product. This off-flavor was objectionable in puree mixtures containing from 15 to 30 per cent diseased roots, depending upon whether the roots used in the mixtures were severely, moderately, or mildly diseased.

LIFE CYCLE AND HABITS OF THE SIX-SPOTTED LEAFHOPPER

Osborn (13) has worked out the life history of the species and described the five nymphal instars in considerable detail. He found that under Maine conditions there are probably three complete broods each year, each one requiring about 27 days from the time the egg is laid until the new adult appears. There has been considerable uncertainty and some disagreement concerning the way in which the insect passes the winter (10, 11, 13).

In a previous report, Hervey and Schroeder (6) pointed out that in western New York the leafhopper overwinters on winter grains and grasses in the egg stage. In the field the eggs begin to hatch on the overwintering host early in May and the insect is found on these plants until about July 1. This is illustrated graphically in Fig. 5, which indicates the hatching time of the eggs and the development of the nymphs and adults in winter barley for the years 1946 through 1948. As the insect reaches the adult stage, it begins to migrate to other plants. This migration is complete by July 1 when the grains approach maturity and no longer offer a suitable source of food. The

only exception to this order of development was encountered in 1947 when an occasional adult was collected in a few grain fields in May as the eggs were hatching. These individuals either overwintered as adults or flew into the area from regions farther south where development was completed earlier. The former assumption is more likely since adults have been collected in the field as late as December after temperatures had dropped to 10° F. It is possible, therefore, for a few individuals to survive the winter in sheltered locations. All other evidence strongly suggests that the insect normally overwinters in the egg stage in this area.

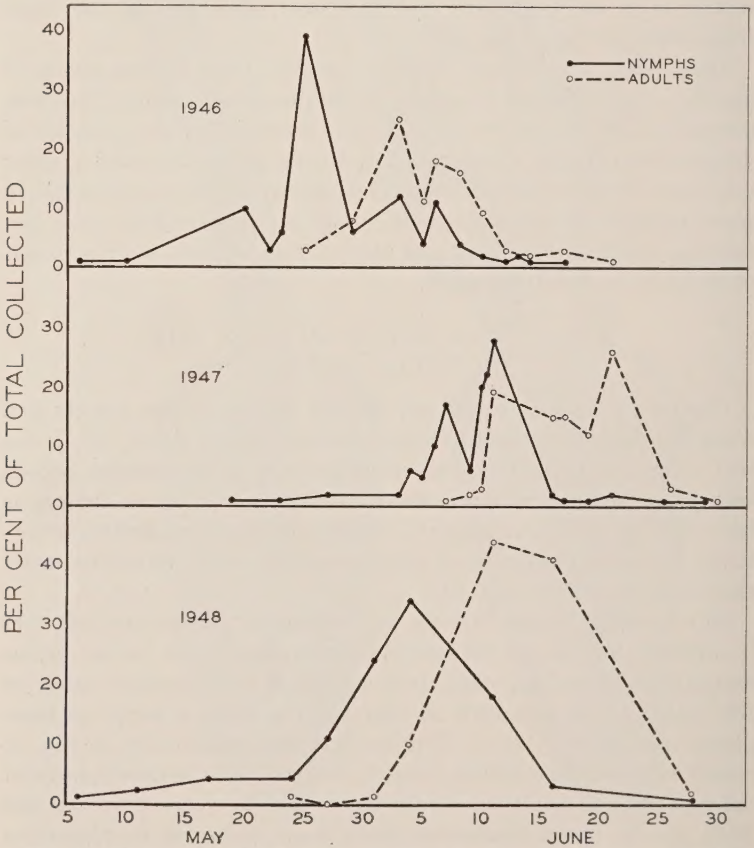

Fig. 5.—The spring development of the six-spotted leafhopper on winter barley in the vicinity of Geneva, N. Y., based on sweeping records 1946 through 1948.

In the course of this study the leafhopper populations have been determined on such crops as winter grains, grasses, and carrots at intervals throughout the season. These population counts were obtained with a standard insect sweeping net by holding it at arm's length and making from 10 to 20 semi-circular sweeps. The collections were made on warm sunny days, when the temperature was 70° or above and the air quiet. This method proved to be a simple and accurate means of determining leafhopper populations in these studies.

Leafhopper collections made in grain fields during May and June have frequently shown a considerable variation in population between fields within the same immediate area. This indicated that the insect preferred one type of grain to another. In order to test this assumption, an experiment was started in the late summer of 1947. A field of grass sod was laid out in randomized block design, consisting of four $^1/_6$-acre plots in each of four blocks. The field was plowed except for one plot in each block which was left in grass. The three remaining plots in each block were planted to winter barley, rye, and wheat. A 10-foot alley was maintained free of vegetation around each plot.

Leafhopper population data from this experiment were obtained in three ways, namely, (a) sweeping records during the autumn when the leafhoppers migrated to the grain fields to lay eggs, (b) rearing the insects in the greenhouse from a number of soil plugs 5 inches in diameter containing the respective plants and taken at random from each plot during the following March, and (c) sweeping records in May after hatching had taken place.

The results (Table 1) indicate that the greatest number of leafhoppers occurred in the barley plots. These records, supported by field observations, establish the fact that when the insects have a choice of grains and grasses for hibernation, barley is preferred. The order of preference following barley was rye, wheat, and grass. The low leafhopper counts obtained in the spring collections in the rye plots probably are not an accurate representation of the population present. Rye grows more rapidly than does wheat or barley early in the season; consequently, it was difficult to sample properly by sweeping because of its greater height. The low population in the grass plots could have been due in part to the fact that the grass was old and thus probably not as attractive for feeding and oviposition in the autumn.

When the insects reach the adult stage on the overwintering hosts, they migrate to other plants, including carrots. The infestation starts at the time the carrot seedlings emerge from the soil in June when an

occasional adult is found. The infestation remains at a low level for several weeks and then rises at a very rapid rate to reach a peak in late July and early August. This build-up of the population is due almost entirely to migration of the insects from other plants within the area. The rapid increase in leafhopper abundance appears to coincide with a corresponding rapid increase in carrot foliage. From the peak in July or early August the population declines rather gradually until harvest in October or November.

Table 1.—The Relative Preference of the Six-spotted Leafhopper for Various Grains and Native Grass as Overwintering Hosts, Geneva, N. Y., 1947–48.

Host plant	Adults collected Nov., 1947, number per 10 sweeps	Insects reared in greenhouse March, 1948, number per sample*	Adults and nymphs collected May, 1948, number per 10 sweeps
Barley	69	19	42
Wheat	28	3	12
Rye	49	12	1
Grass	6	1	4
Least difference required for significance: (19:1)...	23.2	6.4	9.7
(99:1)...	33.3	9.1	13.9

*Sample consisted of a circular plug of soil, 5 inches in diameter, containing the respective plants.

OVERWINTERING OF THE VIRUS

There are two possible means by which the virus may be carried through the winter; one is in the body of the overwintering adult and the other is in the infected overwintering host plants.

Kunkel (10) has reported that some individual vectors may retain the virus for as long as they live. Some individuals under laboratory conditions have remained viruliferous for over 100 days. This possibility is not the most important one, for it has been demonstrated that the insect, under western New York conditions, normally overwinters in the egg stage. Kunkel has further shown that the virus is not carried in the leafhopper egg. The most important means of overwintering the virus, therefore, are the numerous host plants listed by various workers (4, 10, 18, 19). This host range includes a multitude of ornamental, vegetable, and weed plants. Of these only the biennial and perennial hosts are important from the standpoint of overwintering the virus and providing a source of primary inoculum for the leafhopper in the spring.

Common plantain, wild carrot, chicory, dandelion, perennial sow thistle, and various species of wild aster and field daisy are some of the overwintering weed hosts commonly found in and around the hibernating quarters of the leafhopper in western New York. Of these, the one most frequently found infected in the early spring is the common plantain. Additional hosts can be found, but generally are not so important except possibly in a few special individual fields. Most of the infected weed hosts found in the early spring usually can be distinguished from the healthy ones by the upright growth habit, some distortion in the older leaves, and the yellowish bushy top growth (Figs. 6 and 7). If in bloom, the flowers are distorted.

CONTROL OF CARROT YELLOWS WITH DDT

Since carrot yellows in western New York is transmitted solely by the six-spotted leafhopper, it is obvious that it might be possible to control the disease by controlling the leafhopper. Considerable work has been done along this line on lettuce yellows, also caused by the aster yellows virus. Some of the earlier work involved the use of dusts containing rotenone, pyrethrum, and sulfur. All of these dusts gave some control of the leafhopper and the disease (11, 14). Further impetus was given this type of work by the discovery that DDT was especially effective against leafhoppers in general.

In 1945 Smith, *et al.* (21) showed that DDT aerosols were effective in killing the six-spotted leafhopper. Since then various other favorable reports on DDT have appeared in this connection. Granovsky, *et al.* (5) tested a 5 per cent DDT dust, with and without yellow copper oxide, and concluded that both formulations gave satisfactory results in reducing the leafhopper population and the resulting carrot yellows. Pound and Chapman (15) in 1947 found that three applications of a DDT spray gave a significant reduction in carrot yellows and a corresponding increase in yield. Ashdown and Watkins (1) tested various formulations of DDT for lettuce yellows control and concluded that the most satisfactory treatment was a 5 per cent DDT dust applied at 5-day intervals from the time the rows were visible until three weeks before harvest. Hervey and Schroeder (7) found that DDT sprays were more effective than dusts and that a petroleum oil emulsion increased the effectiveness of the former.

1946 EXPERIMENTS

DDT was first tested for carrot yellows control in western New York in 1945. It was found in these preliminary tests that DDT re-

FIG. 6.—Aster yellows on common plantain, *Plantago major* L., in early spring, infection having taken place the preceding autumn. Diseased plant above shows leaf distortion, chlorosis, vein-clearing, and bushy top growth; healthy plant below.

duced the leafhopper population to a minimum within a few hours after the application, but it was noted that the insect started to build up again within a day or two, and within a week to 10 days approached the original population. Observations also revealed that the insect was present on carrots in varying numbers throughout the season from

Fig. 7.—Aster yellows on wild carrot, *Daucus carota* L., in early spring, infection having taken place the previous autumn. Diseased plant above shows the fernlike nature of the leaves and the yellowed new shoot growths; healthy plant below.

seedling emergence until harvest. It appeared from these early observations that the control of yellows with DDT would require rather frequent applications throughout most of the growing season. Accordingly, in 1946, an experiment was carried out in which a DDT spray was applied at weekly intervals from June 24 until the first week in September, a total of 11 applications. The experimental plan consisted of six eight-row plots, approximately $^1/_{100}$ acre in size, which were paired with untreated plots of the same size. Data were obtained from the four center rows of each plot and the results are shown in Table 2.

TABLE 2.—THE CONTROL OF CARROT YELLOWS BY MEANS OF 11 DDT SPRAYS APPLIED WEEKLY AT INTERVALS STARTING JUNE 24, FLINT, N. Y., 1946.

Treatment	Yellows, per cent	Disease index†	Soft rot, per cent	Total yield, tons per acre	Av. weight per root, pounds
None	57*	34*	6.3**	17.9	0.32
6 pounds DDT 50% wettable powder to 100 gals. water	9	7	1.8	18.7	0.35

†Obtained by grading plants into six arbitrary classes based on disease severity and assigning weighted values to each class; thus, when all plants were healthy, the index was 0, when all were dead, the index was 100.
*Differences significant at 1 per cent level.
**Differences significant at 5 per cent level.

This schedule of DDT treatments gave a marked reduction in the incidence of yellows and in the severity of the disease. The percentage of soft rot also was reduced in the treated plots. Differences in yield and weight per root were not significant, but it should be pointed out that in this and all subsequent experiments every plant, regardless of size or disease severity, was included in the total weights. In a commercial harvest many of the diseased roots would be left in the ground or would be discarded, for reasons previously mentioned.

In another experiment in 1946 a comparison was made between several different dust schedules. The plots were ¼ acre in size and arranged in random order in each of four blocks. A 5 per cent DDT dust containing 2 per cent mineral oil was applied with a self-propelled duster at the rate of 40 pounds per acre. The schedules followed and the results obtained are given in Table 3. All plots showed a significant reduction in yellows. The degree of control was rather unsatisfactory, however, even in the plot which received a total of five applications. Insect collections made at intervals during the progress of the experiment showed that the dust gave a high immediate kill of the leafhopper

but lacked residual effect and the insects built up rapidly following each application. The leafhopper population was also very high in this field and at its peak reached about 40 insects per sweep of the net in the untreated area.

Later in the season an effort was made to prolong the effectiveness of DDT by the inclusion of an adjuvant. The materials tested were a commercial oil emulsion[4] and 40 per cent polyethylene polysulfide.[5] In this test the DDT-adjuvant combinations were used in two applications. The materials were applied with a power sprayer with two nozzles per row at the rate of about 150 gallons per acre.

TABLE 3.—THE EFFECT OF VARIOUS DDT DUST SCHEDULES ON THE CONTROL OF CARROT YELLOWS, FLINT, N. Y., 1946.

Dates of application*					Yellows at harvest, per cent
July 23	July 31	Aug. 8	Aug. 21	Sept. 1	
–	–	–	–	–	38
+	+	–	–	–	32
+	+	+	–	–	28
+	+	+	+	–	17
+	+	+	+	+	20
Least difference required for significance (19:1)					5

*Applications made on dates showing + sign.

Each treated plot was bordered by an untreated plot of the same size. At the time of the first application the leafhopper population was at its peak and the disease incidence was approximately 20 per cent. The percentage of yellows at harvest is given in Table 4. These data show that the DDT-oil spray was the most effective treatment. Leafhopper counts made in these plots during the course of the experiment (Table 5) also revealed that both the immediate and residual action of the DDT-oil was better than with the other two treatments. Of

TABLE 4.—THE RELATIVE EFFECTIVENESS OF THREE DDT SPRAY FORMULATIONS ON THE CONTROL OF CARROT YELLOWS, FLINT, N. Y., 1946.

Materials in amount per 100 gallons*	Yellows at harvest, per cent
None	61
4 lbs. DDT 50% wettable powder	44
4 lbs. DDT 50% wettable powder, 2 gals. Orthol K oil emulsion	24
4 lbs. DDT 50% wettable powder, 1 pint Omilite	34

*Treatments applied July 30 and August 12.

[4] Orthol K oil emulsion, made by the California Spray Chemical Co.
[5] Omilite, made by the Goodrich Chemical Co., 1946 formulation.

TABLE 5.—THE EFFECT OF THREE DDT SPRAY FORMULATIONS ON THE LEAFHOPPER POPULATION IN CARROTS, FLINT, N. Y., 1946.

DATE COLLECTED	NUMBER OF LEAFHOPPERS PER 10 SWEEPS			
	Check	DDT	DDT–Orthol K	DDT-Omilite
July 29	174	174	174	174
First Spray Applied July 30				
July 31	277	29	9	20
Aug. 2	169	17	3	8
5	156	66	20	85
9	160	121	91	122
Second Spray Applied August 12				
Aug. 13	164	7	1	7
16	110	10	7	18
21	78	55	23	41
23	90	47	19	25
26	61	44	22	25
29	81	41	23	37
Sept. 4	51	41	24	36

special interest in this experiment is the fact that two applications largely prevented further spread of yellows over the 20 per cent present when the experiment was started.

The 1946 investigations showed that yellows could be reduced by frequent applications of DDT. It was also found that the leafhopper abundance in carrots was largely restricted to a period of three to four weeks. This fact suggested the possibility of obtaining control with only a few treatments applied when the leafhopper population was approaching or at its maximum. It also was demonstrated in the 1946 experiments that the addition of an oil emulsion to the DDT spray increased its effectiveness.

1947 EXPERIMENTS

In 1947 an experiment was designed to determine whether a DDT-oil spray would give sufficient protection against the disease when timed to cover the peak in population. A DDT dust program also was included for comparison. The plots were ¾ acre in size and were located in random order in each of three blocks. The spray was applied at the rate of 125 gallons per acre with an orchard sprayer using a portable six-row boom with two nozzles per row. The dust was applied with a two-row self-propelled duster at the rate of 40 pounds per acre. The first application was made August 5 when the carrots were 4 to 6 inches high and when the leafhoppers were just beginning to increase in numbers. Two subsequent applications were made on August 14 and August 27.

The results of this experiment (Table 6) demonstrated that it is possible to obtain effective control of yellows with the DDT-oil spray mixture by carefully timing the applications to cover the peak in leafhopper abundance. The dust proved less effective than the spray. Leafhopper and yellows counts made during the course of this experiment are illustrated graphically in Fig. 8. It should be noted that some in-

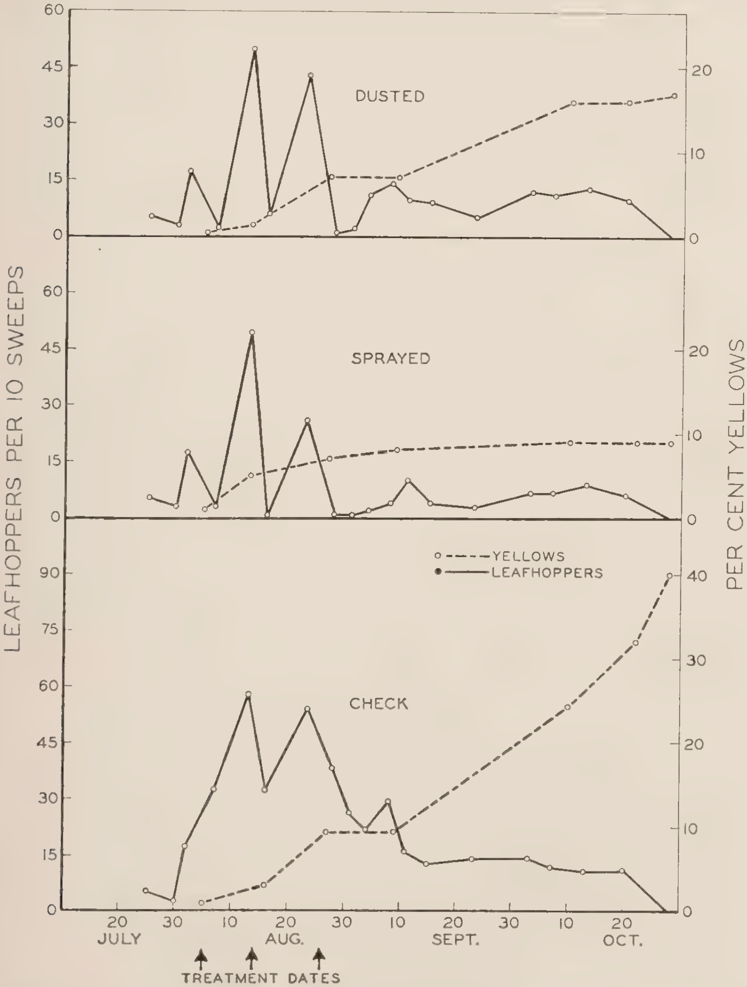

Fig. 8.—The effect of DDT dust and spray applications on leafhopper populations and the development of carrot yellows, Seneca Castle, N. Y., 1947.

fected plants were already present in the field when the first treatment was applied. The disease continued to develop and spread throughout the remainder of the season in the untreated plots. Disease development on the sprayed plot was checked, with little further increase, after the treatments were started. This was also true of the dust-treated plots, but the results were less striking. Fig. 8 also shows the ability of the population to recover following the setback caused by the treatment. This is especially noticeable during the period of maximum abundance. The nymphal stage of the insect is highly susceptible to DDT. It is significant in this connection that the nymphs were never collected in sweeping DDT plots after the treatments were started. The increased effectiveness of the DDT-oil spray was further indicated by the low percentage of yellows developing after a storage period in carrots apparently healthy at harvest (Table 6).

Table 6.—The Control of Carrot Yellows With DDT Spray and Dust Treatments.*

Treatment	Yellows at harvest, per cent	Disease index†	Yield, tons per acre	Yellows developing after storage period, per cent‡
None	39.6	18.9	15.0	46
5% DDT dust	18.0	9.1	15.9	27
4 lbs. DDT 50% wettable powder to 100 gals. water + 2 qts. Orthol K	8.3	4.0	15.6	9
Least difference required for significance (19:1)	6.0	3.2	NS	—

*Treatments applied August 5, 14, and 27.
†See Table 2 for explanation.
‡These roots were selected as healthy at harvest and were grown in the greenhouse after a storage period.

1948 experiments

In the 1948 experiments the DDT-oil spray was compared with a regular DDT spray and a DDT dust at each of two locations. The experiments were identical in all respects except that three applications were made in experiment 1 and four in experiment 2. The plots were ½ acre in size and arranged in random order in each of three blocks. The methods of application were the same as those described for the 1947 experiment. The results (Table 7) confirm those of the previous year in that the best treatment was the DDT-oil combination. This gave 75 to 80 per cent control of carrot yellows. The leafhopper population and the development of yellows in these

two experiments are shown in Figs. 9 and 10. The first of the four sprays applied in experiment 2 was made before the leafhopper started to increase appreciably. This proved to be too early and probably did not contribute to the control of the disease.

The effect of the treatments with respect to DDT residue and flavor was also investigated. Representative samples from each of the four

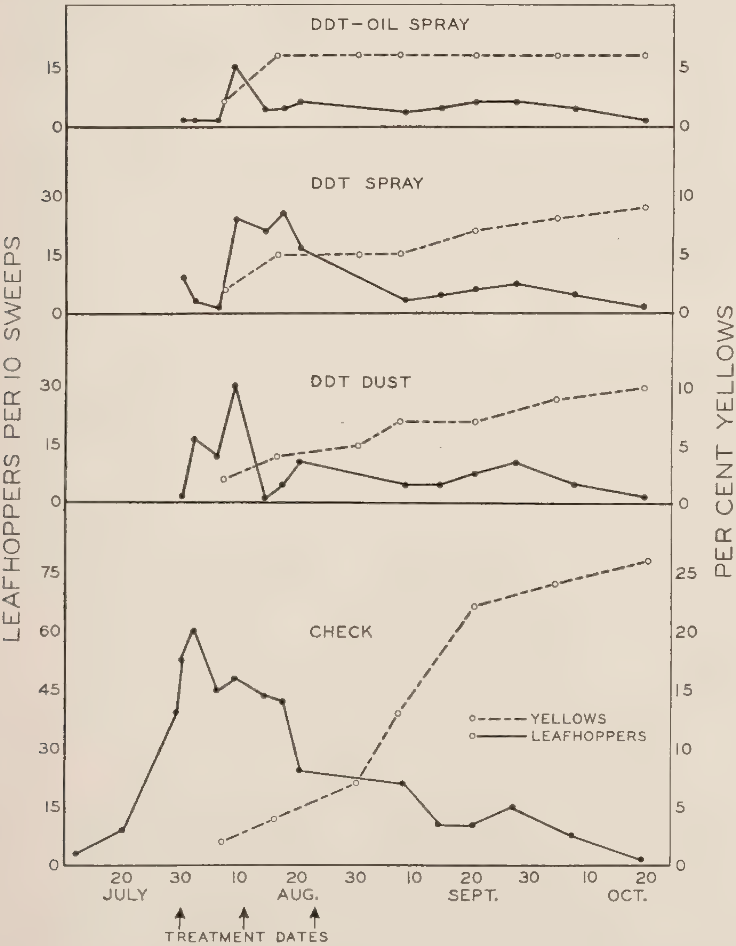

FIG. 9.—The effect of DDT dust and spray treatments on leafhopper populations and development of carrot yellows, experiment 1, Flint, N. Y., 1948.

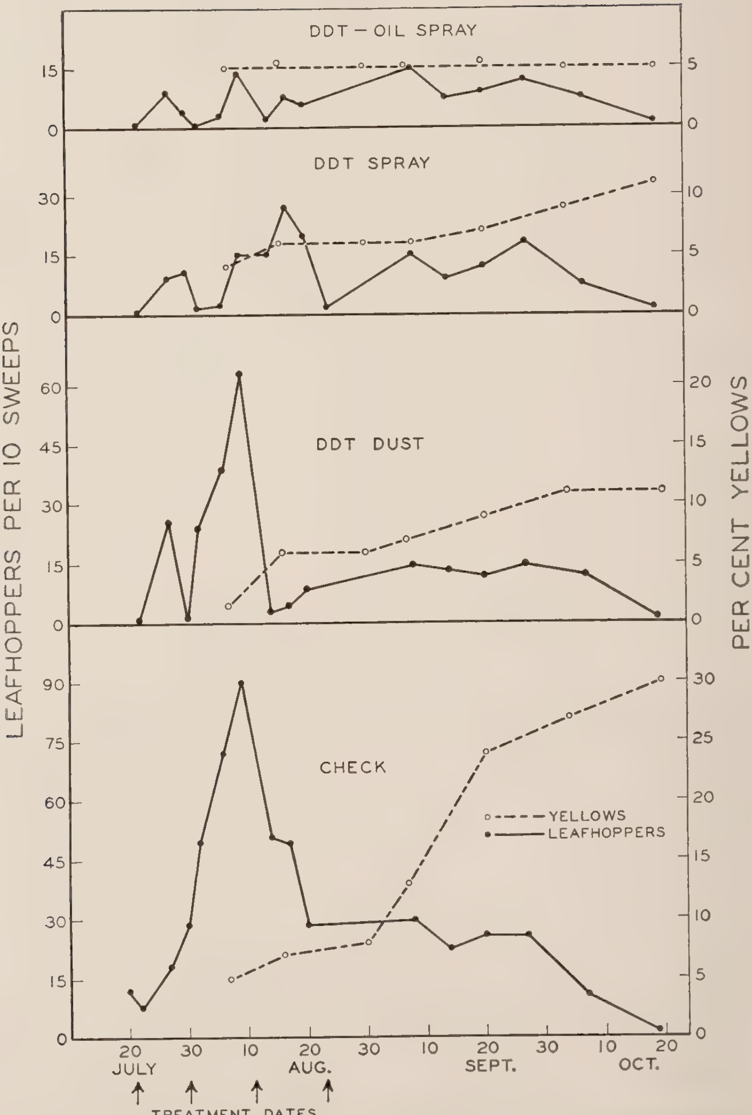

FIG. 10.—The effect of DDT dust and spray treatments on leafhopper populations and development of carrot yellows, experiment 2, Flint, N. Y., 1948.

treatments were taken at harvest from experiment 1. DDT analyses[6] were made on raw carrots, after they were carborundum peeled, and on the processed product. A trace of DDT, less than one part per million, was found on raw carrots before and after peeling. None was detected in the processed product. Samples from each of the four treatments also were canned and subjected to several taste panels. Carrots from the plot treated with the DDT-oil, which contained about 6 per cent yellows, were rated the highest; and those from the nontreated plots which contained about 26 per cent yellows were rated lowest. Those from the other two treatments were not significantly inferior to the DDT-oil lot.

TABLE 7.—THE CONTROL OF CARROT YELLOWS OBTAINED IN TWO EXPERIMENTS WITH APPLICATIONS OF DDT SPRAYS AND DUSTS TIMED TO COVER THE PEAK IN LEAFHOPPER POPULATION, FLINT, N. Y., 1948.

Treatment	Experiment 1*		Experiment 2†	
	Yield, tons per acre	Yellows, per cent	Yield, tons per cent	Yellows, per cent
4 lbs. DDT 50% wettable powder, 100 gals. water	16.5	9.3	15.4	10.7
4 lbs. DDT 50% wettable powder, 2 qts. Orthol K emulsion, 100 gals. water	20.0	6.4	16.3	5.1
5% DDT dust	18.0	9.6	16.5	11.4
None	17.1	26.3	15.1	30.2
Least difference required for significance:				
(19:1)	NS	3.9	NS	3.2
(99:1)		5.8		4.9

*Treatments applied July 30 and August 11 and 23.
†Treatments applied July 21 and 30 and August 11 and 23.

VARIETAL REACTION

The possibility of some inherent resistance or tolerance among the different carrot varieties to the yellows disease was investigated. In 1945 numerous domestic varieties and strains were tested in randomized blocks under field conditions. As has been reported previously by other workers (9, 24), Morse's Bunching variety was found to be the most resistant and the Chantenay types the least. Greenhouse and field tests of approximately 100 varieties and strains of both domestic and foreign carrots planted in randomized block designs have failed to reveal any variety showing significantly less yellows than Morse's Bunching.

[6] A modification of the Schecter-Haller colorimetric method was used.

Fourteen domestic varieties and strains of carrot were tested in randomized block design under field conditions in 1946, 1947, and 1948. The results are summarized in Table 8. It is interesting to note that in these experiments where the varieties were intermingled, as in a randomized block design, certain varieties and even strains exhibit significantly different amounts of the disease. Not much difference existed among the strains of Chantenay variety, with the possible exception of one, Chantenay Improved Long, which showed significantly less disease than some of the others. Two strains, Morse's Bunching and Nanchan, appeared to be the most resistant and Long Orange the most susceptible. Some introductions from China tested along with Long Orange in 1948 were even more susceptible. Of the three strains of Morse's Bunching included in the three years' test,

TABLE 8.—THE RELATIVE SUSCEPTIBILITY OF VARIOUS VARIETIES AND STRAINS OF CARROT TO THE YELLOWS DISEASE IN THE FIELD, 1946, 1947, AND 1948, GENEVA, N. Y.

Variety	Strain	Percentage of yellows			Three-year average
		1946	1947	1948	
Chantenay Improved Long	—	24.7	37.7	7.7	23.4
Chantenay Red Core (Coreless)	—	26.3	47.5	11.0	28.3
Chantenay Red Core	1	32.7	43.8	9.0	28.5
Chantenay Red Core	2	41.8	40.8	15.3	32.6
Chantenay Red Core	3	41.6	51.9	9.6	34.3
Imperator Long	—	25.6	45.0	13.6	28.1
Danvers Red Core	—	29.0	37.7	10.3	25.7
Nanchan	—	18.3	22.3	5.6	15.4
Morse's Bunching	1	13.8	23.0	6.3	14.4
Morse's Bunching	2	18.4	28.3	4.1	16.9
Morse's Bunching	3	35.7	39.9	11.7	29.1
Yellow Belgian	1	28.4	25.1	3.0	18.8
Yellow Belgian	2	46.0	48.9	10.7	35.2
Long Orange	—	58.0	69.0	25.5	50.8
Least difference required for significance: (19:1)		3.9	21.0	6.5	8.3
(99:1)		5.2	28.0	8.7	11.0

two consistently exhibited less disease than the other. The two strains of Yellow Belgium also differed somewhat in susceptibility. On the basis of these tests, it would appear possible to select for more tolerance or resistance to this disease.

Selfed progeny from disease-free carrots selected in the field from Morse's Bunching and Nanchan were planted in random order in the

field with the parent varieties. Some selections developed more yellows and others less than the parents. Here again the indications are that it might be possible to increase resistance through selection and breeding.

Whether this apparent field resistance is inherent or not is questionable. In greenhouse tests where an apparently field-resistant variety such as Morse's Bunching and a susceptible variety such as Long Orange were caged separately with viruliferous leafhoppers, the differences have not been nearly so noticeable as in the field. In fact, both varieties became 100 per cent infected, although the incubation period was slightly longer in the case of Morse's Bunching. This would indicate that the resistance or tolerance observed in the field with mixed planting is more likely due to vector preference rather than an inherent physiological resistance. Further experiments are needed to confirm this conclusion. Meanwhile work is being continued on selection for resistance under field and greenhouse conditions. The question of vector preference is also being studied.

DISCUSSION AND PRACTICAL APPLICATIONS

The prevalence of the carrot yellows disease from year to year is influenced by various factors affecting the virus and the leafhopper vector. The leafhopper passes the winter as an egg which is laid during the autumn on various varieties of winter grains and to a lesser extent on native grasses. It is quite possible that weather conditions during this period influence the rate of oviposition and the subsequent population level the following year. It should also be pointed out that since winter grain fields are the favorite overwintering habitat of the insect, the greater the number and extent of these fields, the better are the chances that the overwintering population would be high. This is true especially if the grain fields are in the immediate vicinity of carrot fields harvested in the fall. Likewise, in the spring the closer the carrot fields are located to the grain fields, the greater are the chances of their being subjected to an early and heavy migration of the leafhopper from the grains.

It has also been shown that after hatching in the spring the insects remain on the grains and grasses until the adult stage is reached or until the grains or grasses become mature. They then migrate to other more succulent plants, including carrots. If the overwintering hosts were known to be heavily infested with leafhoppers, it might be advantageous to treat them with DDT to reduce the population before

migration takes place. It should be understood, however, that it is unsafe to use DDT on any crop which is to be utilized for livestock feed because of the residue problem.

Since the virus cannot be carried in the egg, it is evident that the only way the newly hatched leafhoppers can become infective in spring is by acquiring the virus from the infected overwintering hosts. These host plants are found along ditch banks, fence rows, field roads, and even within the fall-planted grain fields. Many of the adult insects which move into the grain fields in the fall to lay eggs carry the virus and it is possible for them to infect many of the weed hosts present in the grain at that time. In the spring these infected weeds serve as a source of the virus so that the leafhoppers may become infected before they move to the carrot fields. This would tend to result in the early establishment of the disease in the carrots and would thus predispose the planting to high infection by harvest. It would, therefore, probably reduce the chances of early infections if the weed hosts were removed before the insects could feed on them. This might be accomplished in the grain fields with some recently developed herbicides.

The use of DDT for killing the leafhopper offers considerable promise as a practical control measure for carrot yellows. It has given a good immediate kill and will reduce the population of the insect to a very low point within a few hours after being applied. One difficulty encountered in the use of the material has been its lack of appreciable residual effect. This is due in part to the feathery nature of the carrot leaf which makes it difficult to maintain a toxic deposit. There is also the problem of keeping the new foliage protected at this time when the carrots are growing rapidly. Some success has been attained in prolonging the effectiveness of DDT by adding petroleum oil emulsion to the DDT spray. This combination has increased the leafhopper kill and given a significantly higher control of yellows than that obtained with either a regular DDT spray or a 5 per cent DDT dust.

It should be noted that after DDT is used, no leafhopper nymphs are recovered for the remainder of the season. This means that the DDT prevents breeding of the insect in carrots and, therefore, any further infestation must be a result of the flight of leafhopper adults from areas outside the carrot field.

The experiments conducted in 1947 and 1948 show that three applications of the DDT-oil spray put on at approximately 10-day intervals to coincide with the population peak gave 75 to 80 per cent yellows control. It is possible that with a high leafhopper population,

such as occurred in 1946, one or more additional applications would be required for satisfactory disease control. On the other hand, it should be pointed out that the experiments discussed here have not involved the entire planting of carrots in which they were located. The remainder of the field was not treated and thus served as a nearby source of leafhoppers for reinfestation of the treated plots. It seems entirely probable that better control would be obtained if the whole field were treated, which would be the case in a commercial operation. It is not certain, therefore, that more than the three treatments suggested above would be required.

The timing of the treatments depends on the leafhopper migration to the carrots. During 1947 and 1948 the time of the first application was about the first of August, but it is probable that this date might vary somewhat from year to year depending on seasonal conditions and the rate of growth of the carrots. The most accurate means of timing the treatment is by making leafhopper counts at intervals with an insect sweeping net. By this means it is possible to determine when the migration of the insect from other plants to carrots occurs and when the population approaches the peak period.

The possibility of obtaining a practical and heritable resistance to yellows appears remote at the present time. Much of the apparent resistance in the field appears to be the result of a vector preference rather than physiological resistance, for when the varieties are not intermingled but are caged separately in the greenhouse the differences are greatly reduced. Further work along these lines, however, is warranted.

SUMMARY

Carrot yellows affects the quality and yield of the carrot crop by stunting the plant, by causing various physiological and structural changes which disfigure the root, and by imparting an unpleasant off-flavor which is objectionable in processed carrots.

The disease is caused by the aster yellows virus which in western New York is transmitted solely by the six-spotted leafhopper. This insect passes the winter in this latitude in the egg stage on plants of the grass family. There is some evidence that an occasional individual survives the winter in the adult stage, but this is thought to be rather rare. Of the various plants available for hibernation, the insect has shown a preference for winter barley. Other plants which serve as winter hosts are rye, wheat, and native grasses. After hatching early

in May, the insect develops on the overwintering host plants and reaches the adult stage during June. It then migrates to various other plants, including carrots. Studies of the infestation in carrots reveal the fact that the insect is present throughout the entire growing period of the crop. There is, however, a well-defined peak which begins in late July or early August and extends for a period of three to four weeks. This observation has been found important in the development of a control program for the disease.

The virus, which is not carried in the insect egg, passes the winter in various species of infested perennial and biennial weeds. The leafhopper becomes infected in the spring only after feeding on one of these diseased plants. The disease is first noted in carrots during July and increases rather gradually from then until harvest.

Control of the disease may be effected by killing the leafhopper with DDT. The most effective formulation tested is a combination of petroleum oil and DDT. This mixture when applied three times at about 10-day intervals during the period of peak activity of the leafhoppers has given satisfactory yellows control.

LITERATURE CITED

1 Ashdown, D., and Watkins, T. C. Control of the lettuce yellows disease in New York. *Jour. Econ. Ent.*, **41**: *252–258. 1948.*

2 Dorst, H. E. A revision of the leafhoppers of the Macrosteles group (Cicadula of authors) in America north of Mexico. *United States Dept. Agr. Misc. Pub. 271. 1937.*

3 Folsom, D. Yellows. *Plant Disease Reporter,* **13**: *148–149. 1929.*

4 Frazier, N. W., and Severin, H. H. P. Weed host range of California aster yellows. *Hilgardia,* **16**: *619–650. 1945.*

5 Granovsky, A. A., *et al.* Experiments with DDT conducted by state experiment stations. *United States Dept. Agr. Bur. Ent. and Plant Quar. E–644t. 1945.*

6 Hervey, G. E. R., and Schroeder, W. T. Life cycle of *Macrosteles divisus* (Uhl.) in relation to carrot yellows in western New York. *Jour. Econ. Ent.*, **40**: *505–508. 1947.*

7 ————, ————. Factors influencing the control of carrot yellows with DDT. *Phytopath.,* **38**: *314. 1948.*

8 ————, Robinson, W. B., and Schroeder, W. T. Carrot yellows affects flavor of processed product. *Farm Res.*, **14(2)**: *2. 1948.*

9 Ivanoff, S. S., and Ewart, W. H. Aster yellows on vegetable crops and weeds in the Winter Garden region of Texas. *Plant Disease Reporter,* **28**: *972–977. 1944.*

10 Kunkel, L. O. Studies on aster yellows. *Amer. Jour. Bot.,* **13**: *646–705. 1926.*

11 Linn, M. B. The yellows disease on lettuce and endive. *Cornell University Agr. Exp. Sta. Bul. No. 742. 1940.*

12 Newhall, A. G. Some special disease surveys in New York in 1929. *Plant Disease Reporter Suppl.,* **76**: *81–82. 1930.*

13 Osborn, H. Life histories of leafhoppers of Maine. *Maine Agr. Exp. Sta. Bul. No. 248*: *53–80. 1916.*

14 Pepper, B. B., and Haenseler, C. M. Pyrethrum and derris as a control for the six-spotted leafhopper, a vector of lettuce yellows. *Jour. Econ. Ent.,* **32**: *291–296. 1939.*

15 Pound, Glenn S., and Chapman, R. K. Control of aster yellows in carrots by control of *Macrosteles divisus* with DDT. *Phytopath.,* **37**: *18. 1947.*

16 Schroeder, W. T. The yellows disease of carrot. *Farm Res.,* **11(1)**: *1, 5. 1945.*

17 Severin, H. H. P. Carrot and parsley yellows transmitted by the six-spotted leafhopper, *Cicadula sexnotata* (Fall.). *Phytopath.,* **20**: *920–921. 1930.*

18 ——————, and Frazier, N. W. California aster yellows on vegetable and seed crops. *Hilgardia* **16**: *573–596. 1945.*

19 ——————, and Freitag, J. H. Additional ornamental flowering plants naturally infected with California aster yellows. *Hilgardia,* **16**: *597–618. 1945.*

20 ——————. Newly discovered leafhopper vectors of California aster-yellows virus. *Hilgardia,* **17**: *511–524. 1947.*

21 Smith, F. F., Ditman, L. P., and Goodhue, L. D. Experiments with aerosols against some pests of truck crops. *Jour. Econ. Ent.,* **38**: *189–196. 1945.*

22 Smith, R. E. Growing China asters. *Hatch Exp. Sta. Mass. Agr. Col. Bul. No. 79. 1902.*

23 Whetzel, H. H. Diseases of muck crops in New York. *Plant Disease Reporter,* **13**: *115–118. 1929.*

24 Whipple, O. C., and Walker, J. C. No carrot variety escapes both yellows and blight. *Wisconsin Agr. Exp. Sta. Bul. No. 451: 59–60. 1941.*

25 Zundel, G. L. Yellows (virus) on various plants. *Plant Disease Reporter,* **13**: *174. 1929.*